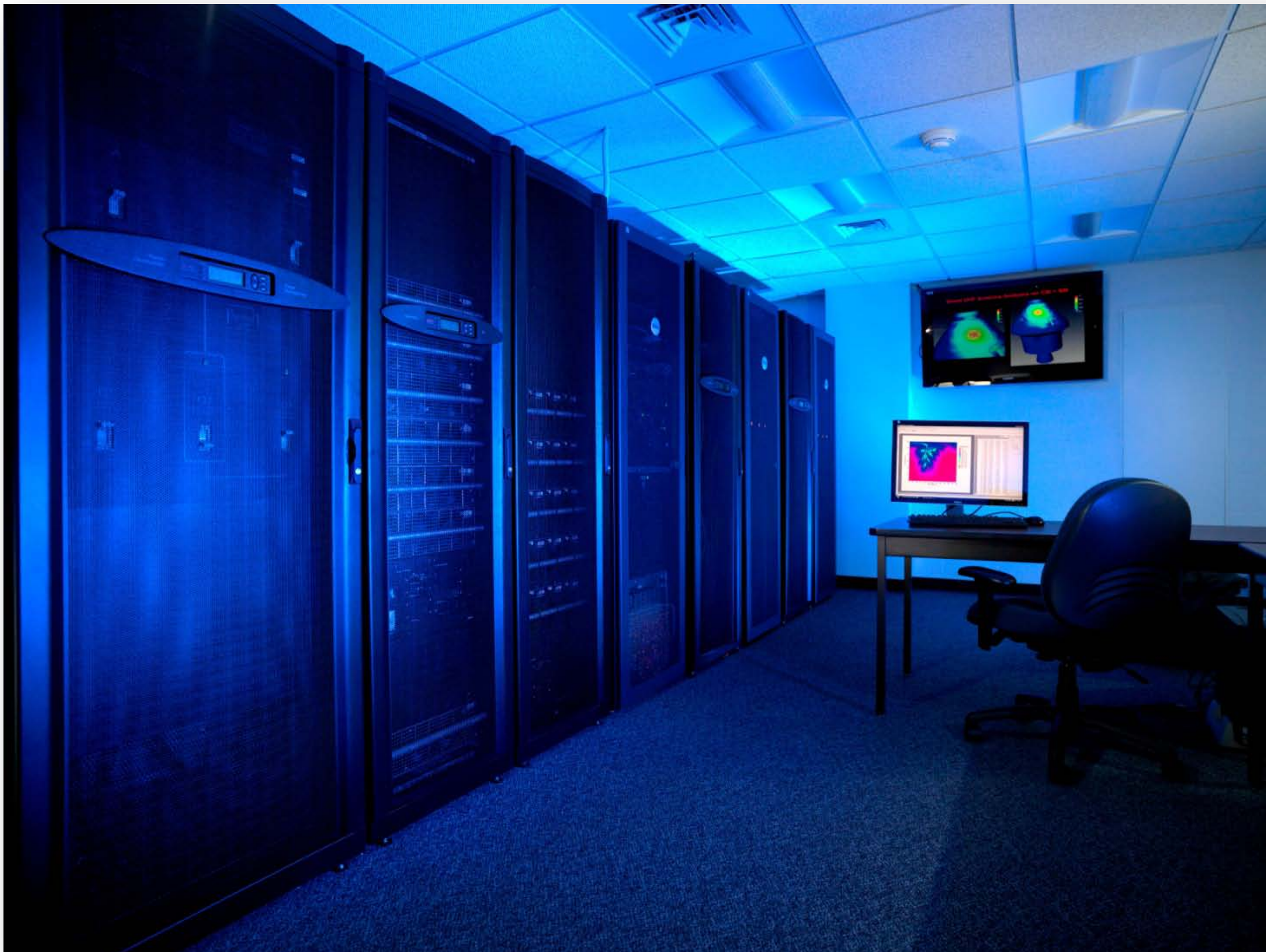
Computational Electromagnetics (CEM) Laboratory

Simulation Planning Guide



National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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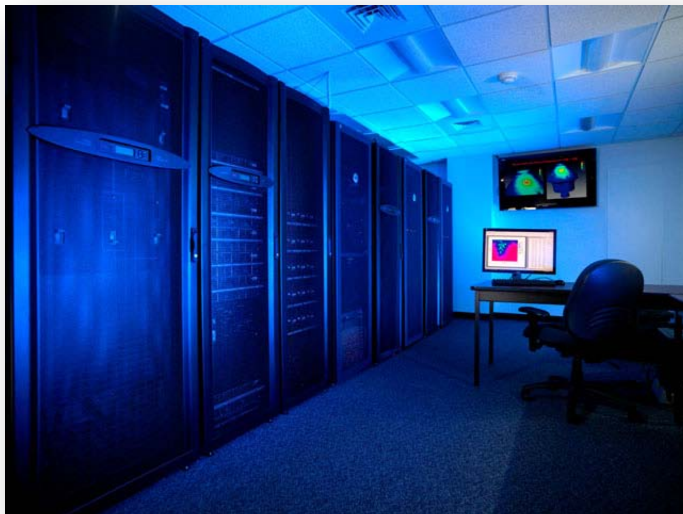
1.0 Computational Electromagnetics Laboratory

The Computational Electromagnetics (CEM) Laboratory is used for full-wave, frequency domain electromagnetic simulations. The laboratory houses a computer cluster dedicated to CEM analysis. The cluster currently contains 476 processors and 1.95 TB of Random Access Memory (RAM). The software is a frequency domain solver that utilizes established integral equation techniques and is a Government Use code that has been developed over the past 25 years at various national laboratories, universities, and the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC). Additionally, the Antenna Test Facility (ATF), located in the same building, is available for performing measurements as part of the analysis process. See Appendix D for additional ATF details. The Communication Systems Simulation Laboratory (CSSL) provides architectures for surface propagation analysis and is available as a complimentary service to the CEM. Details about the CSSL laboratory may be found in Appendix E.

Services Provided*

- Antenna and RF design
- General three-dimensional (3D) frequency domain electromagnetic analysis
- Design and development of microwave devices and antennas
- Near-field and far-field analysis
- Radar cross-section calculations
- Antenna coupling analysis
- Verification of microwave and antenna measurements

* See Appendix A for sample CEM Laboratory services.



The computer cluster housed in the CEM Laboratory

Point of Contact

Technical Monitor, Michael Khayat
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michael.a.khayat@nasa.gov

2.0 Safety and Health

Safety is an integral part of the culture at NASA. Management, leadership, and employee involvement from all organizations is critical to the success of NASA's safety program. While visiting JSC, the requester shall follow all facility-specific safety and health requirements. A facility safety briefing shall be provided to all personnel prior to the start of the test. The safety briefing will include a review of the facility safety rules, potential hazards, and emergency procedures.

3.0 Export Controlled and Proprietary Information

JSC provides for protection of export controlled and proprietary information and hardware throughout the analysis process. The Requester shall clearly mark all export controlled or proprietary hardware items, models, and data provided with a notice of restriction on disclosure or usage. The Laboratory Technical Monitor shall safeguard export controlled or proprietary items from unauthorized use and disclosure and ensure that they remain secure within the laboratory and are properly sequestered. Access to the laboratory is restricted to facility personnel and escorted visitors. Models shall be returned to the Requester or disposed of in accordance with the Requester's instructions at the completion of the activity.

4.0 Simulation Process

The overall CEM analysis is illustrated as a flowchart in Figure 1. Before a structure can be simulated, a computer-aided design (CAD) model of the geometry suitable for electromagnetics analysis must be created. This can be a time-consuming task, especially if the antenna geometry is complicated. This time may be reduced when an existing CAD model of the antenna is provided for the analysis. Additionally, the electrical characteristics of the materials associated with the geometry need to be determined.

Once the antenna CAD is completed, it is used to create a meshed model, which is required by the electromagnetics code. The mesh density is determined by geometrical features and operating frequency. For example, a rule of thumb is to have the edge lengths of each element no more than a tenth of a wavelength at the operating frequency; hence, as the frequency increases, the number of elements in the mesh increases. This, in turn, increases the memory required for the simulation. After a simulation is completed, the results are compared to measured data or previously-run simulated data to determine if the results have converged. If not, the mesh is refined until convergence is achieved.

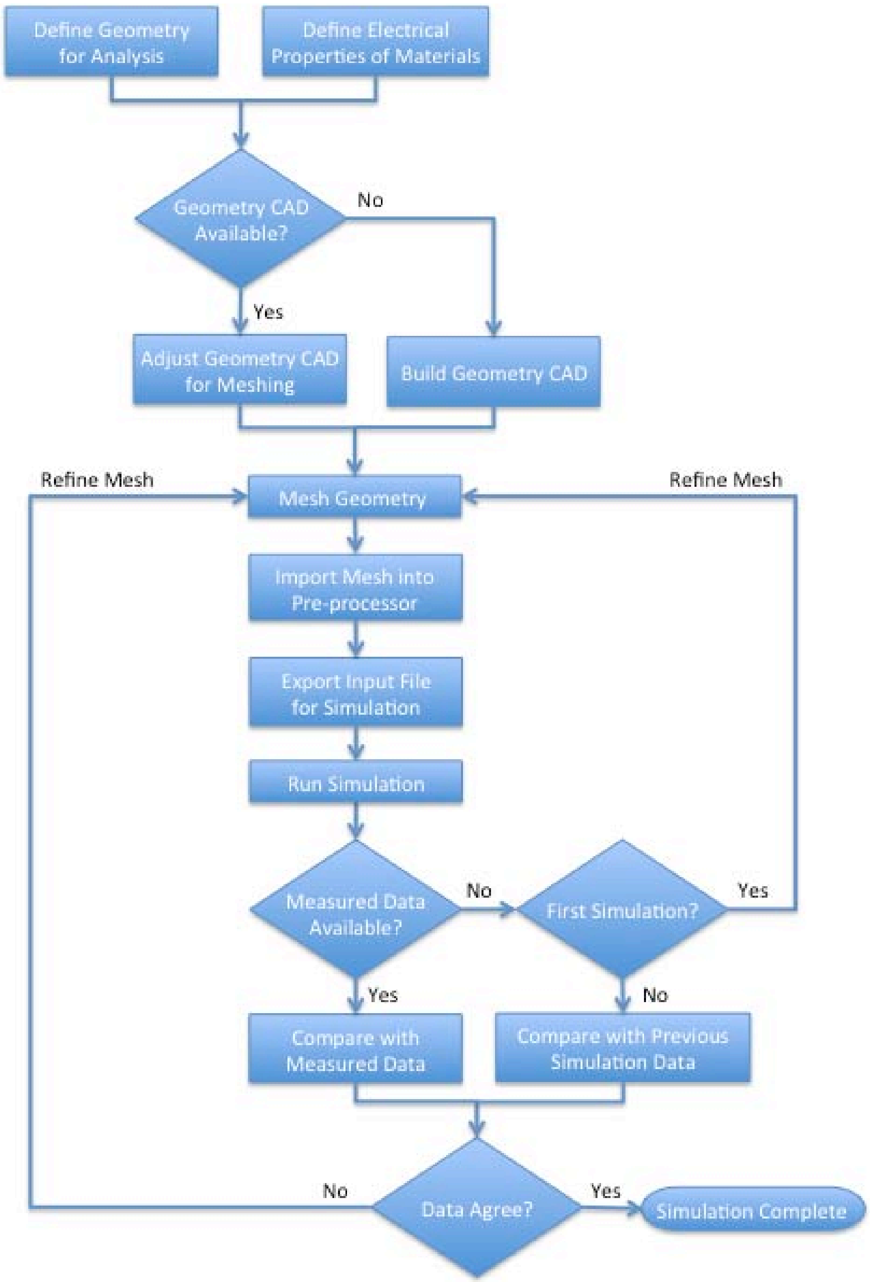
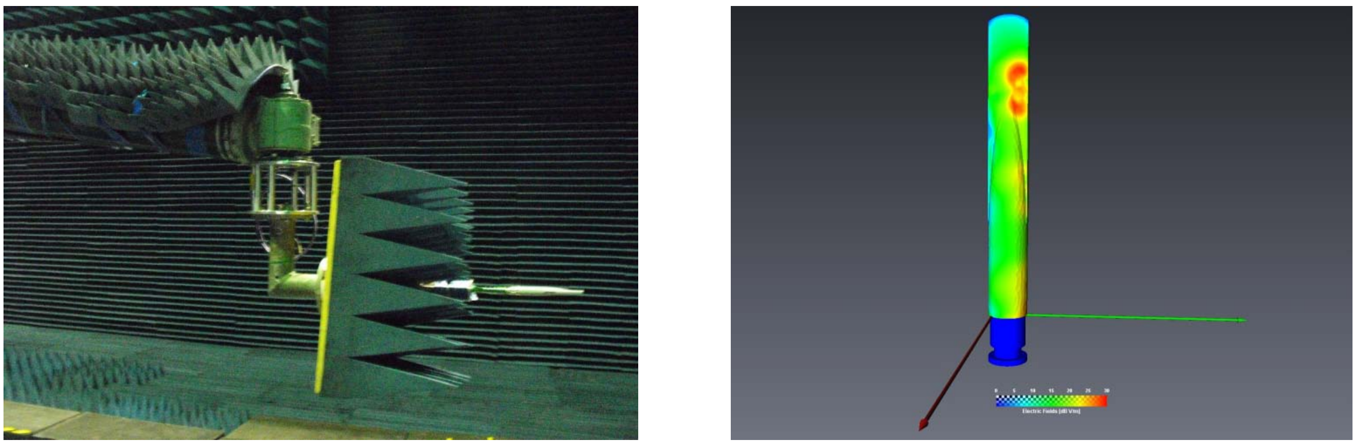


Figure 1. An example process for simulating an antenna on a vehicle (e.g., rocket).

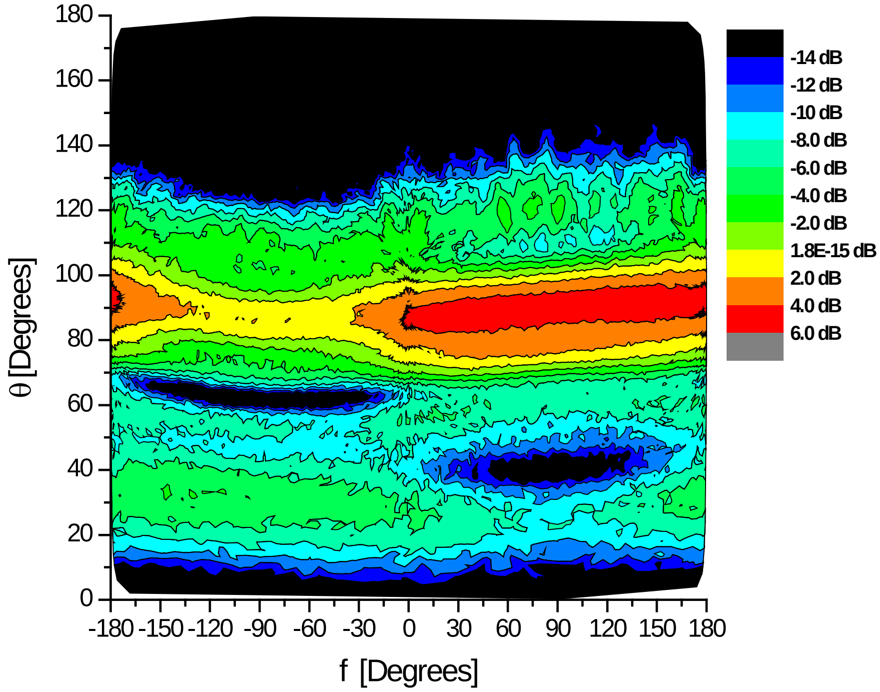
A recent project illustrates this process. The CEM Laboratory personnel were tasked to analyze the antennas on the International Space Station (ISS) External Wireless Communications (EWC) System.

The antenna type, radome, and location were decided prior to the analysis; therefore, the first step in the simulation process was to verify that the CAD model for the antenna was an accurate representation of the antenna. This was achieved by comparing a converged simulation of the antenna with measurements taken at JSC's ATF. Figure 2a shows the measurement setup, and the electric surface currents calculated from a simulation of the EWC antenna are illustrated in Figure 2b. The measured and simulated radiation patterns for the antenna are shown in Figure 3.

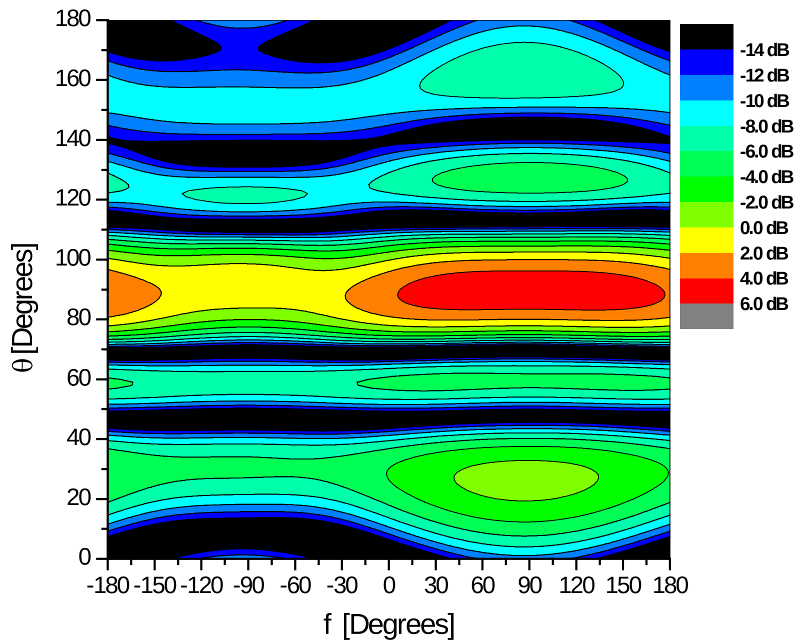


(a) (b)

Figure 2. EWC antenna (a) mounted in the ATF and (b) as a simulated CAD model.



(a)



(b)

Figure 3. (a) Measured and (b) simulated gain patterns of the EWC antenna.

Given the good agreement between the measured and simulated results, the CAD model of the antenna can now be analyzed mounted to the ISS module. The location of the antennas and the geometry of the ISS module are shown in Figure 4. Fortunately, it is not necessary to capture all of the geometrical details in order obtain an accurate CEM solution. The amount of the geometry that needs to be captured will depend on the problem being analyzed, but the visualization tools in the CEM analysis allow complicated CAD models to be simplified. For example, Figure 5 shows the simplified CAD model used for the EWC antenna analysis and the surface currents excited on the structure. The dark blue region in the figure represents surface currents that are approximately 70 dB down from the peak current. Hence, the most important parts of the geometry to model accurately are the dielectric radome covering the antenna and the handrail on which the antenna has been mounted. Figure 6 shows the electric fields excited on the radome, which illustrates the fact that it interferes with the antenna radiation. In addition to being able to view surface plots of the radiation, as shown in Figure 3, the far-field patterns can also be visualized using 3D plots as illustrated in Figure 7.

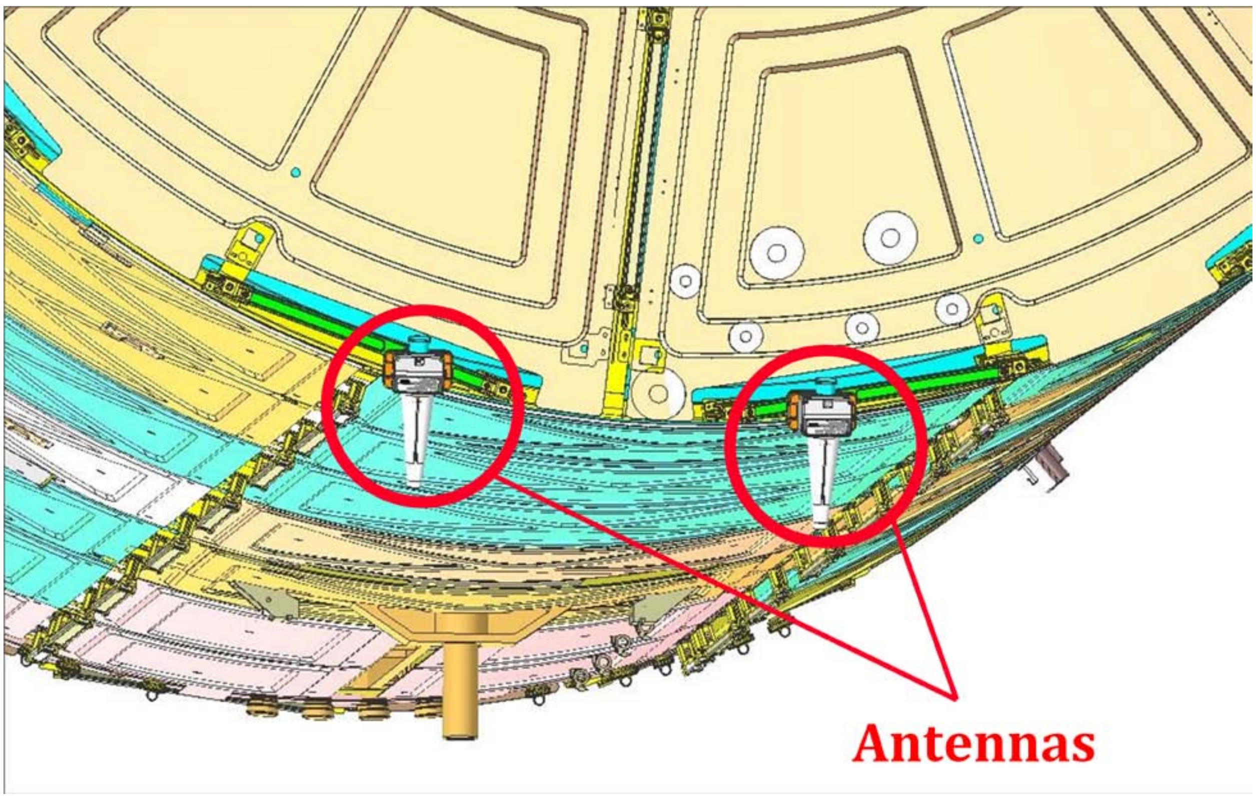


Figure 4. Antennas mounted on ISS module.

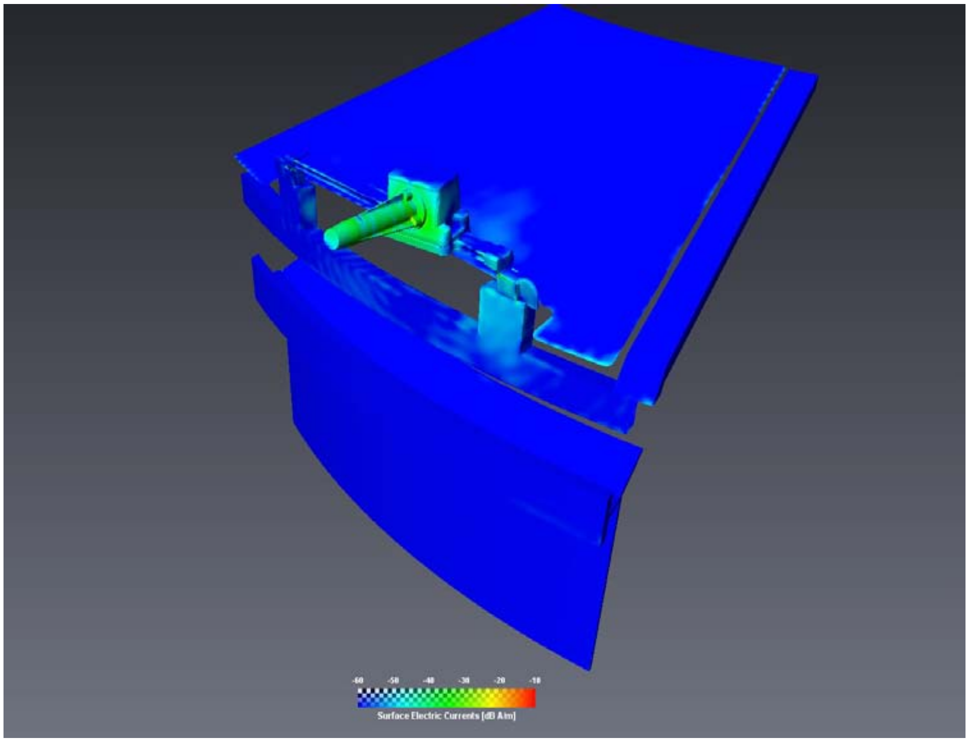


Figure 5. Simulated CAD model of EWC antenna mounted to the ISS module.

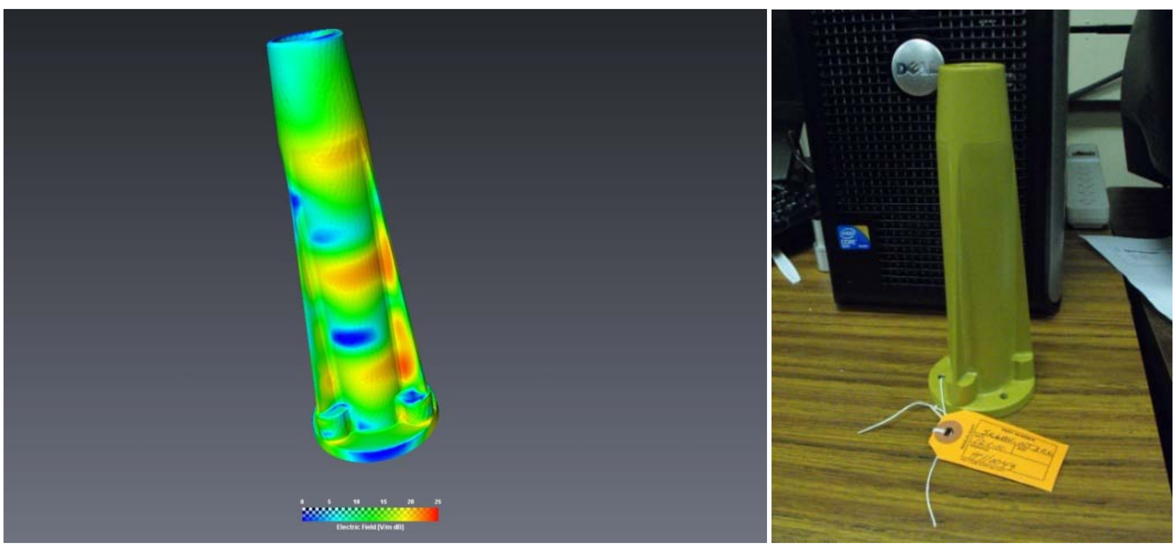


Figure 6. Electric fields excited on the antenna radome.

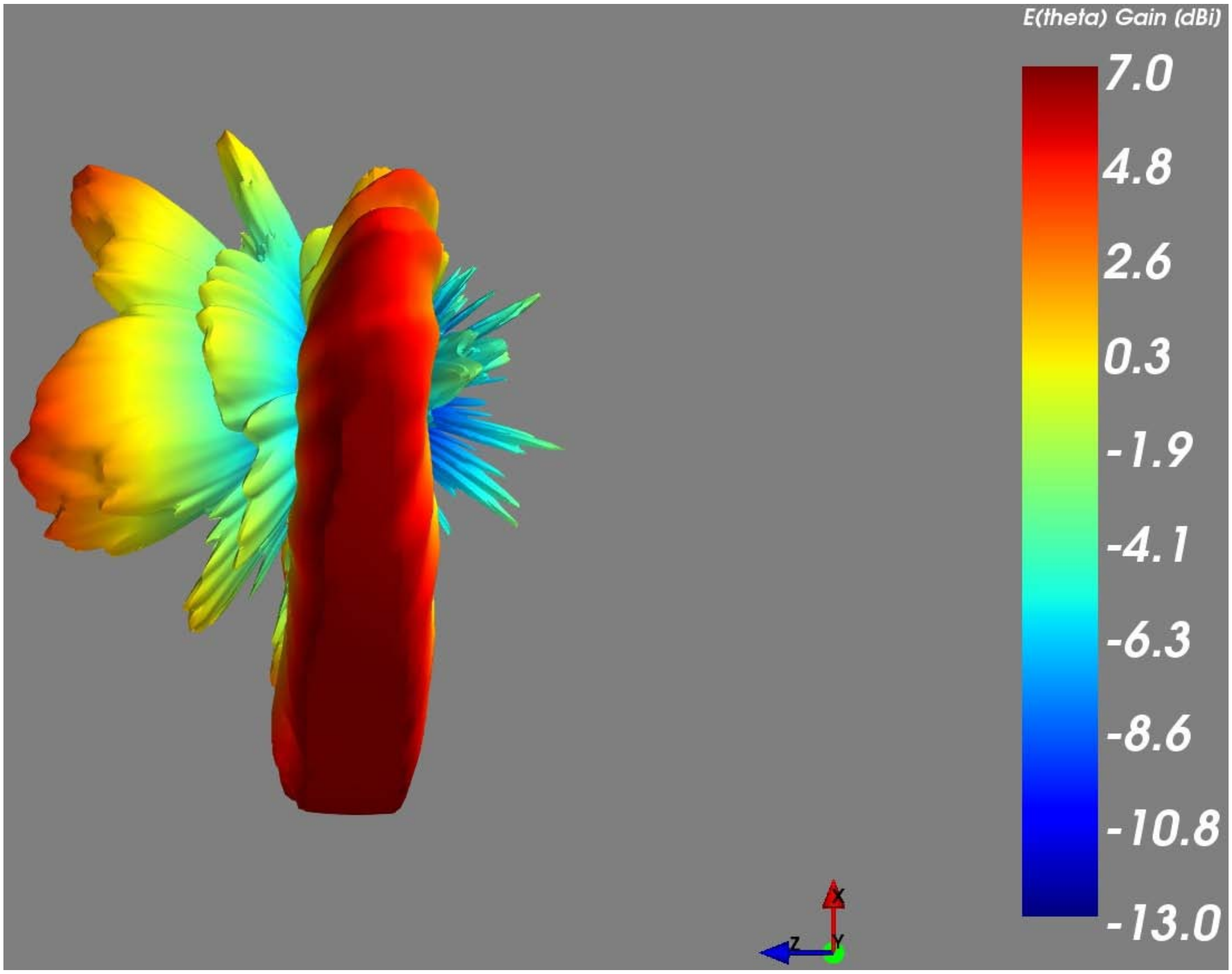


Figure 7. 3D gain pattern of the EWC antenna mounted to the ISS module.

4.1 Simulation Request Phase

The simulation request phase establishes the relationship between the Requester and the Laboratory Technical Monitor. The Requester shall contact the Laboratory Technical Monitor to request a simulation analysis. This contact is necessary to identify the quantity or quantities of interest to be determined during the simulation. Once this is done, an estimated cost and work schedule may be developed and provided to the Simulation Requestor.

Inputs: Requester provides simulation request, identifies simulation goals

Activities: Laboratory Technical Monitor reviews request to determine feasibility

Outputs: Laboratory Technical Monitor delivers estimated cost and schedule to Requester

4.1.1 Simulation Request

The simulation request outlines the scope of the work, objectives, and schedule. A Simulation Request Worksheet is provided in Appendix B. This worksheet addresses the basic requirements for utilizing the CEM Laboratory. It is suggested that the Requester complete this worksheet to facilitate the development of a preliminary cost and schedule estimate. Contact the Laboratory Technical Monitor if you have questions about completing the Simulation Request Worksheet. At a minimum, the request should include the following information:

<u>Scope of Work</u>

A brief description of the simulation requirements, including, but not limited to, the following:

- Desired quantities to calculate (e.g., antenna gains, near fields, input impedance)
- Does a CAD model already exist? (may reduce preparation time)
- Other details to consider (e.g., antenna feeds)
- Data requirements (e.g., primary measurements, data format)

<u>Schedule</u>

Identify the required start and completion dates for the proposed simulation work.

4.1.2 Schedule and Cost Estimate

A cost and schedule estimate, including major milestones, will be delivered to the Requester following receipt of the Simulation Request Worksheet.

4.2 Simulation Preparation Phase

Simulation requirements and schedule are finalized during the simulation preparation phase. The Requester shall provide detailed requirements and documentation to the Laboratory Technical Monitor.

Inputs:	Requester provides requirements and documentation
Activities:	Laboratory Technical Monitor begins planning the work
	Requester sends model to Laboratory Technical Monitor
Outputs:	Requester approves schedule
	Laboratory technical staff begins simulation

4.2.1 Requirements

A complete understanding of requirements is mandatory. Requirements must be defined and reviewed so that the Laboratory Technical Monitor can properly prioritize, plan, and schedule the work. The Requester shall provide a detailed list of requirements, including, but not limited to, the following:

- Simulation model/drawing (CAD preferred)
- Electromagnetic information (e.g., properties of the materials, frequencies, boundary conditions)
- Desired output data

4.2.2 Documentation

The Requester shall provide detailed simulation article drawings (CAD preferred, if available) as requested by the laboratory. Simulation article drawings are used to create models for simulation analysis. We can accept files by e-mail, through a File Transfer Protocol (FTP) site, or via standard mail.

- E-mail drawings to michael.a.khayat@nasa.gov.
- The Laboratory Technical Monitor will send an invitation to the NASA FTP site for uploading and sending files.
- Mail drawings to the Johnson Space Center, Attention: Michael Khayat, Mail Code: ES4, 2101 NASA Parkway, Houston, Texas 77058.

4.2.3 Schedule

A detailed schedule shall be developed by the Laboratory Technical Monitor and approved by the Requester. The schedule shall allow adequate time for review and approval of requirements, preparation for the analysis, and delivery of any models. The schedule of other work and maintenance activities will be reviewed and potential conflicts shall be addressed by the Laboratory Technical Monitor.

4.3 Simulation Execution Phase

Following receipt of the drawing(s), the laboratory technical staff will complete the work.

Inputs:	Laboratory Technical Monitor receives drawing(s)
Activities:	Laboratory technical staff begins simulation
Outputs:	Work completed

4.3.1 Change Request

Changes to the scope of the analysis shall be approved by the Requester. Deviations that result in a major change to the scope of the analysis may require a delta requirements review or a change to the cost and schedule. Changes should be coordinated through the Laboratory Technical Monitor.

4.4 Closeout Phase

Reports and data shall be delivered to the Requester within 30 business days following completion of the analysis. Data delivery may be expedited if requested. The Requester shall make note of data delivery requirements in the Simulation Request Worksheet (Appendix B). The Requester shall notify the Laboratory Technical Monitor upon receipt of the data. Acceptance of the data concludes the activity.

Inputs:	Simulation completed
Activities:	Laboratory Technical Monitor returns model(s) to Requester
	Laboratory Technical Monitor delivers reports and data to Requester
Outputs:	Requester accepts data
	Requester provides feedback

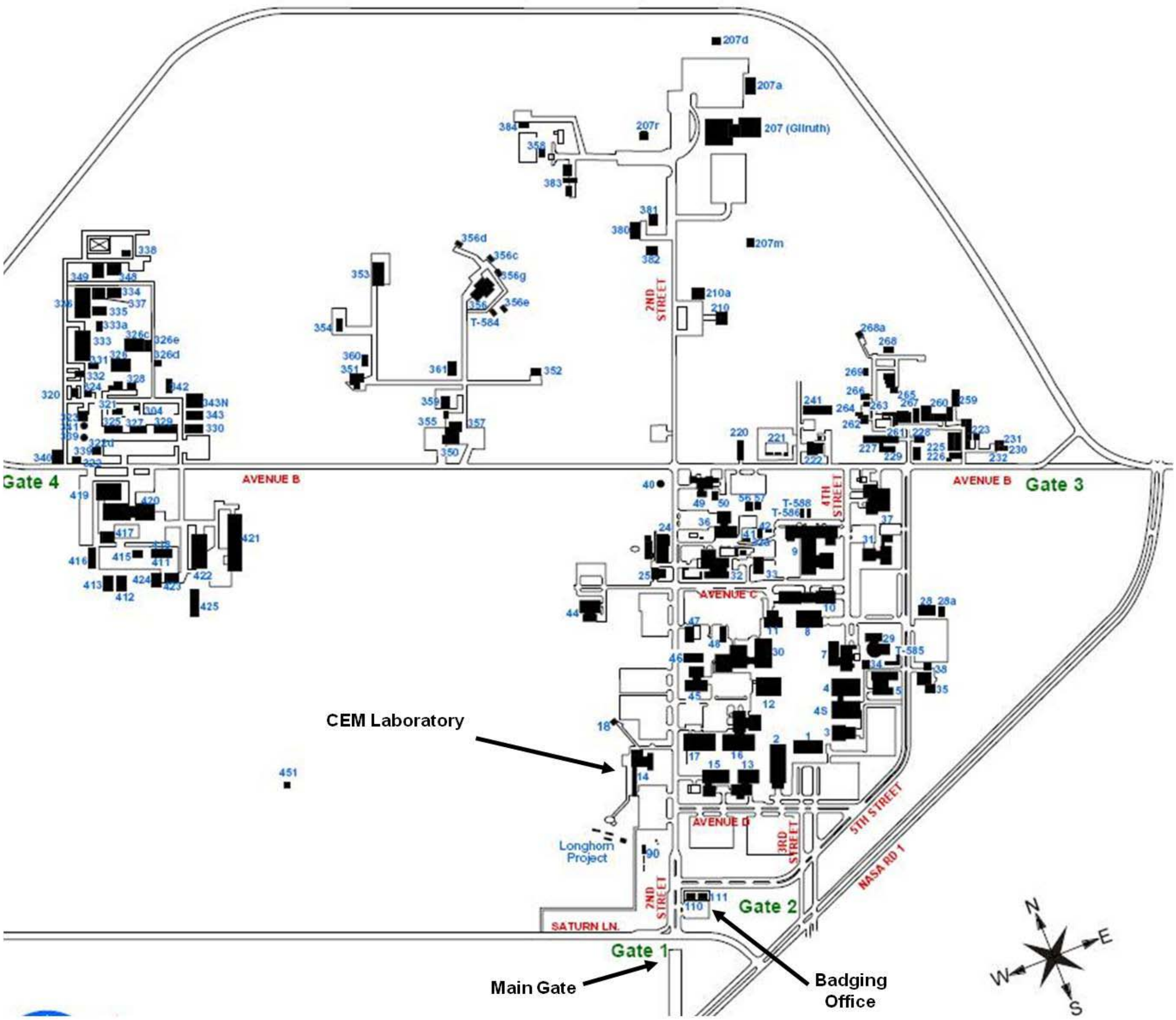
4.4.1 Customer Feedback

The CEM Laboratory encourages feedback from our customers. Evaluation of the services we provide enables continued improvement to our process. Please provide any feedback on our services to the Laboratory Technical Monitor. Your feedback is greatly appreciated.

5.0 Facility Access

Identification badges are required for all persons requiring access to JSC. The Laboratory Technical Monitor or designee will initiate a badge request for all Requester personnel who will be visiting the laboratory. Badge requests must be submitted at least 4 days prior to the visit to prevent badge processing delays. Badge requests for non-U.S. citizens may require a minimum of 30 business days to process. Requester personnel shall arrive at JSC Building 110 to pick up temporary identification badges. Visitors to JSC must show a current picture identification (valid driver's license, U.S. passport, government ID card).

The CEM Laboratory is located in JSC Building 14.



6.0 Roles and Responsibilities

Laboratory Technical Monitor – The CEM Laboratory Technical Monitor coordinates the overall simulation process via discussions with the Simulation Requester.

Laboratory Technical Staff – One or more individuals responsible for performing the analysis per the requirements defined by the Requester.

Requester – The entity requesting a simulation analysis. The Simulation Requester is responsible for providing details for the device that is to be simulated.

Technical Expert – A representative of the Requester with thorough knowledge of the requirements. The Technical Expert also is responsible for verifying that objectives are met and for approving change requests.

Responsibilities Matrix

Item	Requester	Laboratory
Simulation Request Worksheet	Create	Review and provide assistance as needed
Cost and schedule	Approve	Create and sign off
Simulation	Approve requested deviations	Perform simulation
Provide data/results	Notify Laboratory Technical Monitor of data receipt	Deliver to Requester
Review data/results	Approve	

Acronyms

3D	Three-Dimensional
ATF	Antenna Test Facility
AUT	Antenna Under Test
CAD	Computer-Aided Design
CEM	Computational Electromagnetics
CSSL	Communication Systems Simulation Laboratory
dB	Decibel(s)
DEM	Digital Elevation Model
EMC	Electromagnetic Compatibility
EWC	External Wireless Communications
FTS	Flight Termination System
GB	Gigabyte(s)
GHz	Gigahertz
ISS	International Space Station
JSC	Johnson Space Center
lb	Pound(s)
MHz	Megahertz
NASA	National Aeronautics and Space Administration
RAM	Random Access Memory
RF	Radio Frequency
TB	Terabyte(s)
TV	Television

Appendices

A. Sample CEM Laboratory Services

B. Simulation Request Worksheet

C. Laboratory Equipment

D. Antenna Test Facility

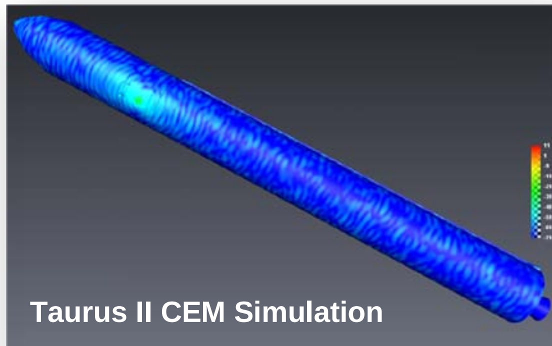
E. Communication Systems Simulation Laboratory

Appendix A Sample CEM Laboratory Services

Large Vehicle Analysis

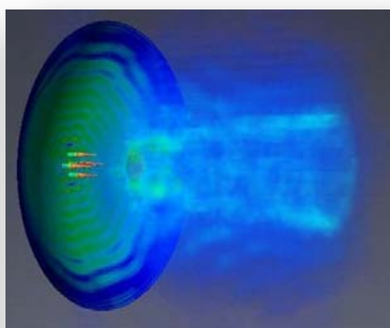
Orbital Space Science Corporation's Taurus II and SpaceX's Falcon 9 Vehicles

Flight Termination System (FTS) Analysis – simulations approved by Range Safety

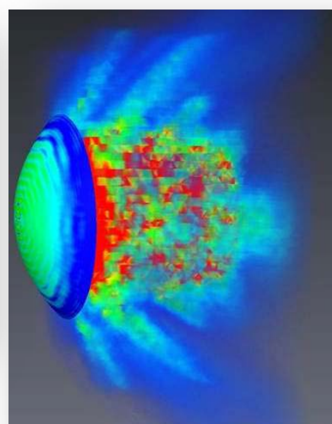


Electromagnetic Compatibility (EMC) Analysis

Cassegrain Dish Antenna Near-Field Analysis



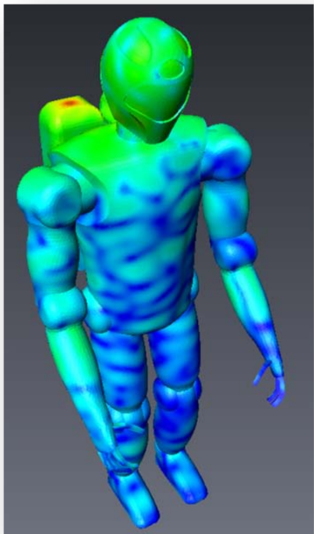
Magnetic Fields

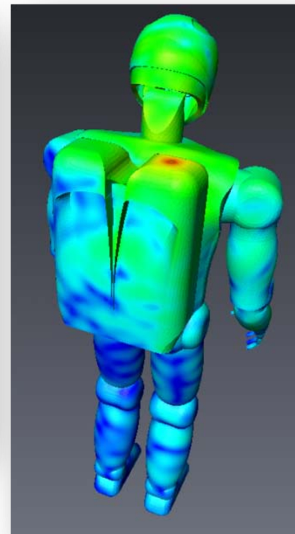


Electric Fields

Antenna Placement Analysis

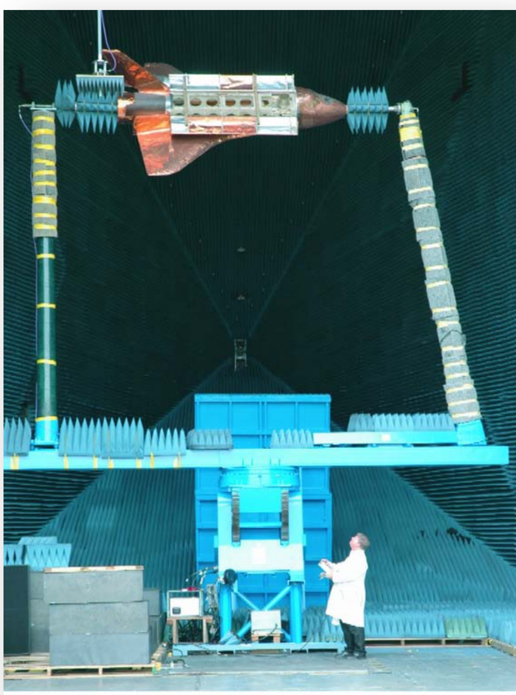
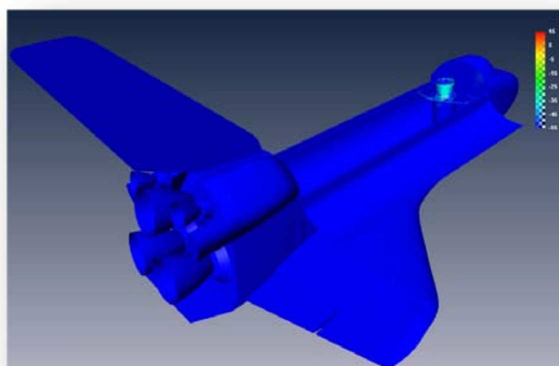
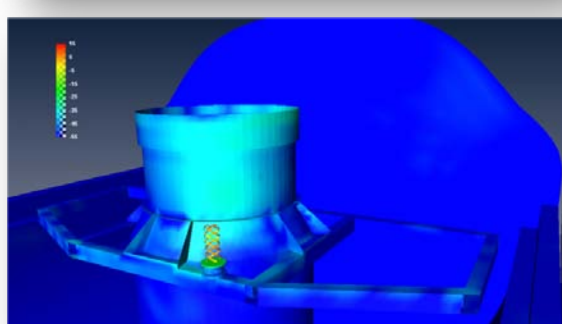
Robonaut II – A monopole located on the backpack





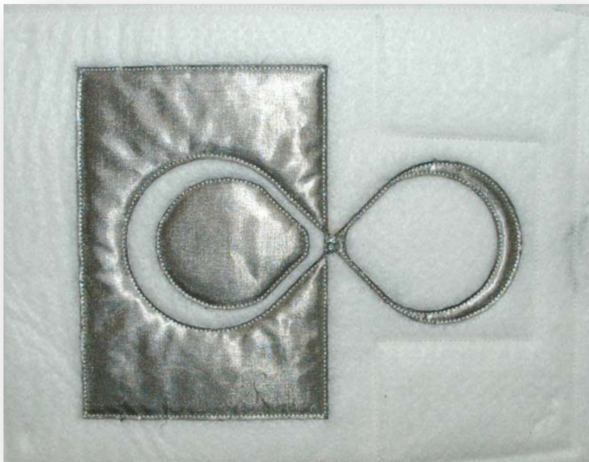
Measurement Validation

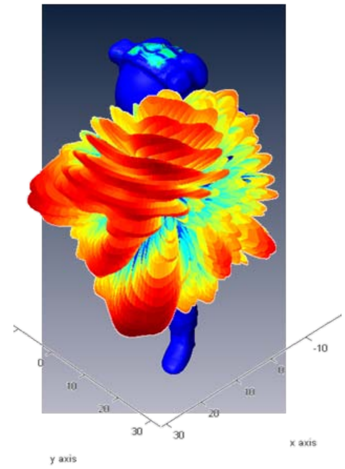
Shuttle Space-to-Space Communication System – Analysis of Space-to-Space Orbiter Radio and Wireless Video System antennas

Antenna Design and Analysis

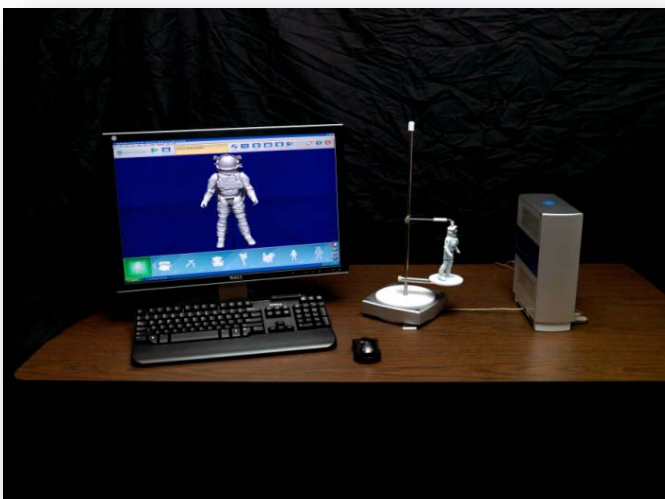
Multiple E-textile antennas attached to an astronaut suit



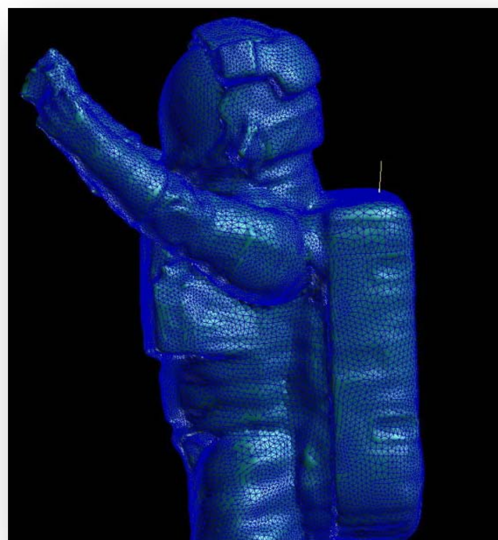


Simulated Radiation Pattern

3D Optical Scanner for the Creation of CAD Models



Optical Scanner



Appendix B Simulation Request Worksheet

Purpose: The purpose of this questionnaire is to provide the Requester with a means of identifying essential elements required to generate a cost and schedule estimate. Please return this form to Michael Khayat, CEM Technical Monitor, michael.a.khayat@nasa.gov.

Contact Information

Test Article Expert:	Contact Information (Phone, E-mail, Address):

Objectives

Scope of Work:	
Proposed Start Date:	Critical Start Date:

Simulation Overview

Total Number of Simulations:	CAD Provided by Requester (Y/N):
Describe geometry CAD that is already available:	
Describe portion of the geometry CAD that is to be built by the CEM Laboratory:	
Desired quantities to be computed in post-processing analysis:	

Data Acquisition and Recording

Data Handling Requirements (storage, expedited delivery, format):

Other Information

List any other information pertinent to the simulation:

Appendix C Laboratory Equipment

Name	Quantity	Specifications
Dell PowerEdge 6850	1	4 dual-core Xeon MP processors, 3.66 GHz, 64 GB RAM
Dell PowerEdge 1950	56	2 dual-core Xeon processors 5160, 3.00 GHz, 16 GB RAM per blade
Dell PowerEdge 1950	20	2 quad-core Xeon Processors X5355, 2.66 GHz, 32 GB RAM per blade
Dell PowerEdge R610	11	E5520 Xeon Processor, 2.26 GHz, 36 GB RAM per blade
Mellanox Infiniscale	1	17.28TBS-QDR Infinichas Switch, 216 port
Processors	480	4 GB RAM per processor

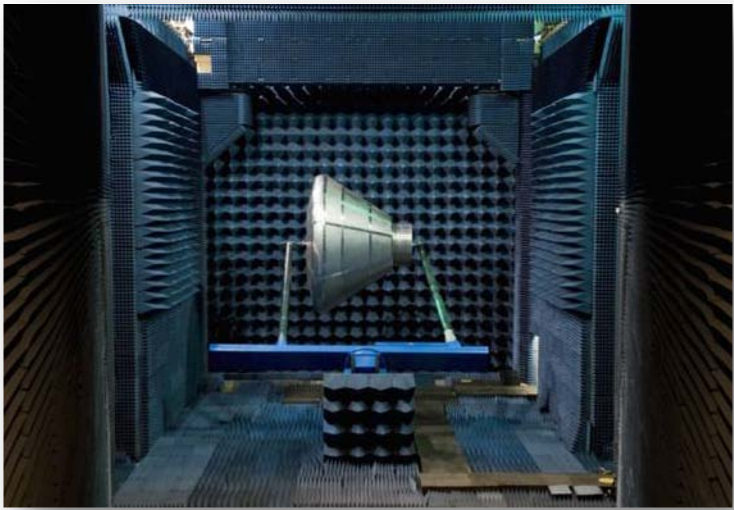
Appendix D Antenna Test Facility

The Antenna Test Facility (ATF) is used to test antenna radiation distribution pattern performance for spaceflight applications in electromagnetic environments conditioned to simulate free space. The frequency range of this activity spans from 200 MHz to 40 GHz. The antenna ranges are used to acquire radiation performance data by taking radiation pattern measurements. The ATF has one Anechoic Chamber and an Outdoor Antenna Range. The Anechoic Chamber houses two antenna test facilities—the Far-Field Test Facility and the Near-Field Test Facility.

Far-Field Test Facility

The Anechoic Chamber's Far-Field Test Facility is uniquely designed to accommodate large test articles, such as spacecraft mockups with antennas mounted on them. The microwave material that covers the wall and door surfaces adsorbs electromagnetic energy, thereby allowing the Anechoic Chamber to simulate a space environment. The chamber is air conditioned, and it has artificial lighting, shielded personnel doors, and a shielded sliding high-bay door that allows for easy entry and exit of large mockups. The chamber has the capability to accommodate lower-frequency testing, down to 200 MHz, in an effort to bring indoors all testing with a frequency range from 200 MHz to 40 GHz.

Near-Field Test Facility



The Near-Field Test Facility within the Anechoic Chamber expands the testing and measurement capabilities of this facility by providing a means of analyzing radiating elements in cases where far-field measurements are impractical due to range length requirements.

Outdoor Antenna Range

While the Anechoic Chamber and the Outdoor Antenna Range are both capable of testing below 1 GHz, the Outdoor Antenna Range serves as the alternate facility in the event of concurrent testing in progress or during maintenance of the Anechoic Chamber.

Point of Contact

Laboratory Manager, Greg Lin
Johnson Space Center
2101 NASA Parkway, Houston, TX 77058
(281) 244-0969
greg.y.lin@nasa.gov

Specifications

Far-Field Test Facility

Parameter	Value
Function/Frequency Range	Measures far-field antenna radiation distribution patterns and principal plane cuts; 200 MHz to 40 GHz frequency range
Dimensions	Flared horn shape (tapered); 150 feet long with a cross section of approximately 40 x 40 feet
Range Length	Approximately 115 feet from tip of apex to Antenna Under Test (AUT)
Antenna Mounting	Single positioner or dual positioner
Load Capability	Single positioner can handle 600 lb; dual positioner can handle 1,200 lb
Maximum Mockup Size	28 feet in length on dual positioner
Radio Frequency (RF) Absorber	12-inch wedge on taper; 12-inch wedge and 36-inch twisted pyramidal on side walls; 12-inch wedge and 18-inch pyramidal on floors; 18-inch cone and 12-inch wedge on ceiling; 6-foot twisted pyramidal on back wall; floor absorber is not bonded to floor to allow for flexible floor layout, depending on application needed
Floor/Working Space	Approximately 3,000 square feet with floor absorber removed; primarily used for test setups involving large mockups
Test Viewing	Closed-circuit television (TV) camera mounted inside the chamber to allow external viewing of test
Range Access	55-foot x 55-foot back wall slides open to allow easy entry and exit of large mockups

Near-Field Test Facility

Parameter	Value
Function/Frequency Range	Measures near-field antenna patterns using raster can; 350 MHz to 4 GHz frequency range
Antenna Mounting	Hydraulic cylinder (AUT fixed in a vertical position during test) or dual tower positioner (AUT not fixed)
Scanning Plane	38 feet by 38 feet
Maximum Antenna Size	28 feet in length on dual tower; 30 feet in diameter on hydraulic cylinder

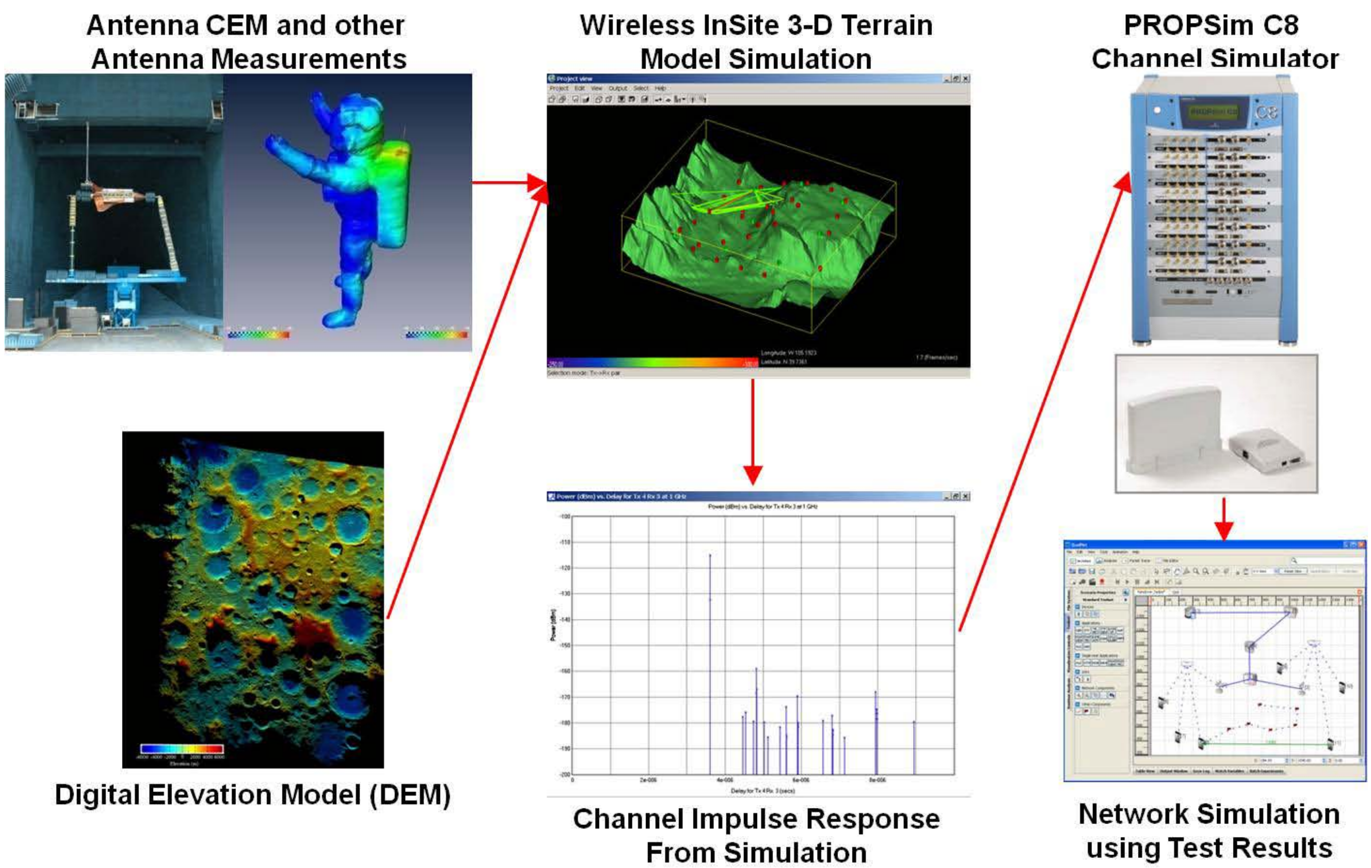
Outdoor Antenna Range

Parameter	Value
Function/Frequency Range	Measures far-field radiation principal plane cuts; 200 MHz to 26.5 GHz frequency range
Antenna Mounting	Single or dual positioner
Range Length	~180 feet from transmit antenna device under test
Maximum Antenna Size	28 feet in length on dual positioner
Load Capability	Single positioner can handle 600 lb; dual positioner can handle 1200 lb

Appendix E Communication Systems Simulation Laboratory

The Communication Systems Simulation Laboratory (CSSL) is utilized to model and simulate the performance of both proposed and actual spacecraft communication systems, subsystems, components, and parts. The laboratory hosts high-fidelity computer models of communication systems, detailed structure models, 3D and planar cuts of antenna patterns, planetary terrain models, and propagation models.

<u>Architecture for Surface Propagation Analysis and Testing</u>



The CSSL makes it possible to integrate antenna data, terrain data, mission profiles, and actual hardware to conduct simulations and make real measurements

Point of Contact

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